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Biological Data to Support Operable Unit 7-13/14 Modeling of Plant and Animal Intrusion at Buried Waste Sites

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ABSTRACT

The purpose of this report is to provide species-specific root measurements and burrow dimensions to support biointrusion modeling activities at the Idaho National Laboratory (INL) Site. Plant roots and burrowing animals are capable of breaching engineered barriers and have the potential to increase migration of hazardous buried waste to groundwater and adjacent land. Studies to assess the long-term impacts of biotic intrusion are expensive and generally impractical. Rather, computer models are used to evaluate the long-term impacts to barrier integrity as a result of physical intrusion by plants and animals. To produce the most accurate simulations, input data for biointrusion models should reflect site conditions as closely as possible. Burrow dimensions for 12 animal species and root measurements for 22 plant species found at the INL Site and in the northwestern United States are presented.

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1. INTRODUCTION

1.1 Purpose

An in-depth review was conducted to identify studies that quantify the attributes of animal burrows and plant roots for species that may inhabit buried waste areas at the Idaho National Laboratory (INL) Site. The purpose of this document is to provide burrow and root data that could be used in modeling the impacts of plant and animal intrusion at the INL. Data for 12 animal and 21 plant species were identified and are discussed in the following sections. Published animal burrow dimensions are presented in Appendix A and plant rooting characteristics are summarized in Appendix B. An example of how biological data were used to model contaminant transport by plants and animals at an INL buried waste site is included in Appendix C.

1.2 Background

Earthen barriers have been widely incorporated as in situ remedies for management of buried waste at hazardous waste disposal facilities. The major function of these protective barriers is to prevent migration and transport of hazardous constituents to groundwater and adjacent land (Cadwell, Eberhardt, and Simmons 1989). Penetration of earthen barriers by animal burrows and plant roots (i.e., biointrusion) has the potential to change water infiltration and erosion patterns that could compromise barrier integrity (Gee and Ward 1997). Subsurface contamination transported to the surface by animal burrowing and plant roots can also result in migration of contamination outside facility boundaries through biological (i.e., food web) and physical (e.g., wind) pathways (Arthur 1982; Arthur, Grant, and Markham 1983; Dabrowski 1973; O'Farrell et al. 1975). The design of engineered features to control and manage intrusion by plants and animals is important to maintaining the long-term function and effectiveness of barrier systems (Gee et al. 1995; Cline, Gano, and Rogers 1980).

Several extended studies have focused on collecting biological data to support the design of engineered barriers (Anderson et al. 1993; Petersen, Link, and Gee 1995; Gee et al. 1995), but study of the long-term impacts of intrusion by plants and animals is difficult and expensive. Therefore, an important aspect of barrier design includes the application of computerized models to evaluate the effectiveness of preventative measures (e.g., installation of capillary barriers and impenetrable gravel layers) and to predict the long-term impacts to barrier integrity as a result of physical intrusion by plants and animals.

Models used to evaluate the potential impacts of biointrusion on barrier performance require, among other things, plant and animal population estimates, animal burrow dimensions, excavated soil volumes and soil physical properties, plant-rooting characteristics, and numerous moisture movement parameters. To maximize model accuracy, input data for both biotic and abiotic parameters should be specific to the site. However, comprehensive data are time consuming and expensive to produce and data applicable to individual sites are not generally available. Model estimates based on poorly researched and incomplete data, on the other hand, have been criticized for deficiencies such as failure to consider all resident species, inappropriate substitution of surrogate species, inappropriate combination of data, and failure to incorporate soil physical properties in the analyses (Smallwood, Morrison, and Beyea 1998).

Historically, biological data used in INL Site modeling activities have been compiled on an ad hoc basis and tailored for specific purposes. Pertinent biological data sets compiled to support previous modeling efforts at the Hanford Site near Richland, Washington (McKenzie et al. 1982), have served as primary sources for input values used in past INL Site intrusion and transport modeling activities (Becker et al. 1998, 1996, 1994; Hampton and Bensen 1996). However, those sources contain limited data for plant and animal species found at the INL Site.

2. ANIMAL BURROW DIMENSIONS

The prevention and management of animal burrowing are of considerable importance in the design of engineered barriers. Burrowing animals have the potential for penetrating protective barriers, thereby mobilizing contamination (Cadwell, Eberhardt, and Simmons 1989; Aurthur and Markham 1983; Rogers, Cline, and Uresk 1978) and altering the rates of surface erosion (Hakonson, Martinez, and White 1982; Ellison 1946). Contaminated subsurface soil brought to the surface is subject to windborne transport off-site, and poses potential threats to humans and wildlife as a result of direct and indirect exposure through the food web (Cline, Gano, and Rogers 1980; Landeen and Mitchell 1981).

Animal burrows have also been investigated as possible conduits for water infiltration that could increase migration of hazardous constituents through earthen barriers to groundwater (Gee and Ward 1997; Cadwell, Eberhardt, and Simmons 1989; Landeen 1994). Soil loosened through excavation can increase moisture-holding capacity and accumulated soil may also act to divert large areas of surface runoff, causing water to pond in low-lying areas and larger burrows (Cadwell, Eberhardt, and Simmons 1989). However, the current body of research indicates that mammal burrows have relatively small impacts on the movement of water through earthen barriers (Gee and Ward 1997).

Smallwood, Morrison, and Beyea (1998) identified a set of "burrowing attributes" important in developing predictive models to evaluate the impacts of biointrusion. Attributes required for each species include (1) the density of animals per unit area, (2) average and maximum burrow depths, (3) burrow volumes, (4) burrow production per animal, (5) distribution of burrow systems with depth, and (6) the rate of subsurface soil to surface excavation. However, data sets containing the complete set of attributes for more than a few species are not generally available. Published data characterizing animal burrows have been previously compiled and applied in the evaluation of biointrusion at Hanford (Cadwell, Eberhardt, and Simmons 1989; McKenzie et al. 1986, 1982; Waugh et al. 1994), but not all species found at the INL Site are included.

The following 16 burrowing animal species have the potential for inhabiting or frequenting buried waste sites at the INL Site:

- Badger (*Taxidea taxus*)
- Burrowing owl (*Athene cunicularia*)
- Coyote (*Canis latrans*)
- Deer mouse (*Peromyscus maniculatus*)
- Great Basin pocket mouse (*Perognathus parvus*)
- Harvester ant (*Pogonomyrmex salinus*)
- Least chipmunk (*Eutamias minimus*)
- Montane vole (*Microtus montanus*)
- Northern pocket gopher (*Thomomys talpoides*)
- Nuttall's cottontail (*Sylvilagus nuttallii*)

- Ord’s kangaroo rat (*Dipodomys ordii*)
- Pygmy rabbit (*Brachylagus idahoensis*)
- Red fox (*Vulpes vulpes*)
- Sagebrush vole (*Lagurus curtatus*)
- Townsend’s ground squirrel (*Spermophilus townsendii*)[1]
- Yellow-bellied marmot (*Marmota flaviventris*)

Burrow dimensions and characteristics for 12 of these species were located in the literature and are summarized in Table 1. Published values for burrow length, diameter, volume, and depth are presented in Appendix A. Burrow density is dependent on species composition, populations, and habitat, so density data from sites other than the INL are less useful. Site-specific values for burrow densities can also be reasonably obtained through field counts. Because populations and species composition vary widely from year to year and habitat to habitat, density data were not compiled in Appendix A. Rather, an example of a successional model in which population densities and soil excavation are estimated for small mammal communities at an INL buried waste site is presented in Appendix C. Studies in which water infiltration data were presented are also indicated in Table 1. However, infiltration measurements and supporting information (e.g., soil characteristics) were not compiled for this report.

[1] Taxonomic classification of this species is under review as *Spermophilus mollis artemisae* (Paiute ground squirrel) (Yensen 2001).

Table 1. Summary of existing burrow data by species and source. (Published data values are presented in Appendix A, Table A-1.)

Species	Reference	Length	Diameter	Total Volume	Depth	Volume with Depth	Density	Amount of Excavated Soil	Water Infiltration
Badger (*Taxidea taxus*)	Anderson and Johns (1977)				x				
	Cline et al. (1982)				x				
	Gano and States (1982)				x				
	McKenzie et al. (1982)				x				
	Lindzey (1976)	x			x				
Deer mouse (*Peromyscus maniculatus*)	Laundre (1989a)		x						
	Reynolds and Laundre (1988)				x	x		x	
	Reynolds and Wakkinen (1987)	x		x	x				
	Sheffer (1941)				x				
Great Basin pocket mouse (*Perognathus parvus*)	Cline et al. (1982)				x				
	Cline, Gano, and Rogers (1980)				x				
	Gano and States (1982)				x				
	Landeen and Mitchell (1981)			x	x			x	

Table 1. (continued).

Species	Reference	Length	Diameter	Total Volume	Depth	Volume with Depth	Density	Amount of Excavated Soil	Water Infiltration
Harvester ant *Pogonomyrmex salinus*	Blom, Clark, and Johnson (1991)				x		x		
	Blom et al. (1994)								x
	Cline et al. (1982)				x				
	Fitzner et al. (1979)				x		x	x	
	Gaglio et al. (1998)				x				
	Mackay and Gaglio (1999)								x
Least chipmunk (*Eutamias minimus*)	Laundre (1989b)	x	x	x	x				
Montane vole (*Microtus montanus*)	Reynolds and Laundre (1988)				x	x		x	
	Reynolds and Wakkinen (1987)	x		x	x				
	Laundre (1989a)		x						
	Lyons (1979)		x						
Northern pocket gopher (*Thomomys talpoides*)	Cline et al. (1982)		x						
	Gano and States (1982)	x			x				
	Turner et al. (1973)	x	x		x				
	Winsor and Whicker (1980)				x		x	x	

Table 1. (continued).

Species	Reference	Length	Diameter	Total Volume	Depth	Volume with Depth	Density	Amount of Excavated Soil	Water Infiltration
Ord's kangaroo rat (*Dipodomys ordii*)	Reynolds and Laundre (1988)				x	x		x	
	Reynolds and Wakkinen (1987)	x		x	x				
	Laundre (1989a)		x						
Pygmy rabbit (*Brachylagus idahoensis*)	Wilde (1978)	x	x		x				
Sagebrush vole (*Lagurus curtatus*)	Mullican and Keller (1986)	x	x		x				
Townsend's ground squirrel (*Spermophilus townsendii*)	Cline et al. (1982)				x				
	Laundre (1989a)		x						
	Laundre (1993)								x
	Gano and States (1982)	x			x				
	Reynolds and Laundre (1988)				x	x		x	
	Reynolds and Wakkinen (1987)	x		x	x				
Yellow-bellied marmot (*Marmota flaviventris*)	Gano and States (1982)	x			x				
	Svendsen (1976)	x			x				
Combined species and general groups	Arthur and Markham (1983)							x	
	Landeen (1994)								x
	McKenzie et al. (1982)			x		x	x	x	

3. PLANT ROOTING CHARACTERISTICS

Evaluating the influences of plant roots on water and contaminant movement within barrier profiles is important in both design and maintenance of barrier systems. Vegetation is commonly established and maintained on earthen barriers to control erosion and water movement. The use of plant cover to control drainage and groundwater recharge has been studied both at the INL Site (Anderson et al. 1993, 1991) and at other waste disposal facilities (Waugh et al. 1994; Mayer, Breedlow, and Cadwell 1981). Although plant roots are important in the formation of voids that channel surface water to deeper depths in earthen barriers, they also have the potential for depleting moisture stored in the barrier profile (Gee and Ward 1997; Anderson et al. 1993).

Roots of some plant species can penetrate earthen barriers deep enough to reach buried waste and thus, become pathways for contaminants to reach vegetative growth at the surface (Arthur 1982; Klepper, Gano, and Cadwell 1985; Klepper et al. 1979, 1978). Once translocated to aboveground vegetative parts, contamination can be transported off-site via physical movement (e.g., tumbleweeds) or by primary consumers through the food web (Dabrowski 1973; O'Farrell et al. 1975).

Plant-root attributes that are important in modeling potential intrusion scenarios include maximum and average root depth, distribution of root-mass with depth, lateral extent and distribution, and the pattern and rate of moisture extraction from the soil profile. Changes in plant community age and transition from annual to perennial species over time have the potential to significantly alter water infiltration and movement (McKenzie et al. 1986; Mckenzie et al. 1982). Therefore, data for plant rooting characteristics in both disturbed and undisturbed soil profiles, and information on successional changes in vegetation (e.g., species composition and density) are also important. Root data for 22 plant species found at the INL Site were located (see Table 2). Published data values for root depths and root distribution with depth are presented in Appendix B. An example of successional change in the plant community at an INL buried waste site is given in Appendix C. Studies in which water extraction data are presented are also indicated on Table 2. However, water extraction measurements and supporting information were not compiled as part of this report.

Table 2. Summary of pertinent plant root data by species and source. (Published data values are presented in Appendix B, Table B-1.)

Species	Reference	Depth	Distribution with Depth	Mass	Lateral Spread	Water Status or Extraction with Depth
Antelope bitterbrush (*Purshia tridentata*)	Klepper, Gano, and Cadwell (1985)	x				
Great Basin wildrye (*Elymus cinereus*)	Abbott, Fraley, and Reynolds (1991)	x			x	
	Anderson and Inouye (1988)	x				x
	Anderson et al. (1993)					x
	Reynolds (1990a)	x	x			
	Reynolds (1990b)	x	x	x	x	
	Reynolds and Fraley (1989)	x			x	
Bottlebrush squirreltail (*Elymus elymoides*)	Abbott, Fraley, and Reynolds (1991)	x			x	
	Reynolds and Fraley (1989)	x			x	

Table 2. (continued).

Species	Reference	Depth	Distribution with Depth	Mass	Lateral Spread	Water Status or Extraction with Depth
Big sagebrush (*Artemisia tridentata*)	Klepper, Gano, and Cadwell (1985)	x	x			
	Waugh et al. (1994)	x				
	Abbott, Fraley, and Reynolds (1991)	x			x	x
	Anderson and Inouye (1988)	x				x
	Anderson et al. (1993)					x
	Link et al. (1994)	x	x			x
	Reynolds (1990a)	x	x			
	Reynolds (1990b)	x	x	x	x	
	Pearson (1965)	x			x	
	Hull and Klomp (1974)	x		x	x	
	Reynolds and Fraley (1989)	x			x	
	Fox, Tierny, and Williams (1984)	x				
Bushy birdbeak (*Cordylanthus ramosus*)	Reynolds and Fraley (1989)	x			x	
Fringed sagebrush (*Artemisia frigida*)	McKenzie et al. (1982)	x				
	Currie and Hammer (1979)	x			x	
	Fox, Tierny, and Williams (1984)	x	x			

Table 2. (continued).

Species	Reference	Depth	Distribution with Depth	Mass	Lateral Spread	Water Status or Extraction with Depth
Bluebunch wheatgrass *(Pseudoregneria spicata)*	McKenzie et al. (1982)	x				
Cheatgrass (*Bromus tectorum*)	McKenzie et al. (1982)	x				
Crested (Desert) wheatgrass (*Agropyron desertorum*)	Abbott, Fraley, and Reynolds (1991)	x			x	x
	Anderson et al. (1993)					x
	Anderson and Inouye (1988)	x				x
	Reynolds (1990a)	x	x			
	Reynolds (1990b)	x	x	x	x	
	Reynolds and Fraley (1989)	x				
Gray rabbitbrush (*Chrysothamnus nauseosus*)	Klepper, Gano, and Cadwell (1985)	x	x			
	Foxx, Tierny, and Williams (1984)	x				
Green rabbitbrush (*Chrysothamnus viscidiflorus*)	Klepper, Gano, and Cadwell (1985)	x			x	x
	Abbott, Fraley, and Reynolds (1991)	x				
	Reynolds and Fraley (1989)	x		x		
Indian ricegrass (*Achnatherum hymenoides*)	Klepper, Gano, and Cadwell (1985)	x				
	Reynolds and Fraley (1989)	x				

Table 2. (continued).

Species	Reference	Depth	Distribution with Depth	Mass	Lateral Spread	Water Status or Extraction with Depth
Needle-and-thread grass (*Stipa* sp.)	McKenzie et al. (1982)	x				
	Klepper, Gano, and Cadwell (1985)	x	x			
	Foxx, Tierny, and Williams (1984)	x				
Jim Hill Mustard (*Sisymbrium altissimum*)	Waugh et al. (1994)	x				
Prickly lettuce (*Lactuca serriola*)	Klepper, Gano, and Cadwell (1985)	x				
Russian thistle (*Salsola kali*)	Waugh et al. (1994)	x	x			
	McKenzie et al. (1982)	x				
	Reynolds (1990b)	x	x	x	x	
	Klepper, Gano, and Cadwell (1985)	x				
Salsify (*Tragopogon dubius*)	McKenzie et al. (1982)	x				
Spiny hopsage(*Grayia spinosa*)	Klepper, Gano, and Cadwell (1985)	x				
	Link et al. (1994)	x	x			x
Streambank wheatgrass (*Elymus lanceolatus*)	Abbott, Fraley, and Reynolds (1991)	x			x	x
	Reynolds (1990a)	x	x			
	Reynolds (1990b)	x	x	x	x	
	Anderson et al. (1993)					x
Turpentine cymnopterus (*Cymnopterus terebinthinus*)	Klepper, Gano, and Cadwell (1985)	x	x			

Table 2. (continued).

Species	Reference	Depth	Distribution with Depth	Mass	Lateral Spread	Water Status or Extraction with Depth
Western wheatgrass (*Pascopyrum smithii*)	Foxx, Tierny, and Williams (1984)	x				
Yellow sweet clover (*Melilotus officinalis*)	McKenzie et al. (1982)	x				
	Foxx, Tierny, and Williams (1984)	x				
General information and plants	Anderson et al. (1993)					x

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Appendix A

Animal Burrow Measurements

Appendix A

Animal Burrow Measurements

A-1. INTRODUCTION

A summary of burrow dimensions for 12 animal species found at the INL Site is presented in Table A-1. The data were compiled from (1) summaries of previously reported data, (2) original studies, and (3) data presented or interpreted by an author to support original work (noted with * in Table A-1). Dimensions that were inferred or calculated from the data presented in the cited source are indicated by ** in Table A-1.

The status of the soil profile (i.e., whether it is disturbed or undisturbed) can influence the depth and configuration of burrows. In most cases, the soil profile status (Table A-1) was either reported directly by the researcher or inferred from the description of the study site. Some investigations include data collected in both disturbed and undisturbed soil profiles. Therefore, data for each are reported separately in Table A-1. Some fossorial species create more than one burrow type (i.e., nesting, hibernation, predator escape, or foraging) and each may vary in general character and configuration. Data reported for individual burrow types are also presented separately in Table A-1.

Table A-1. Summary of published burrow dimensions for animal species found at the INL Site.

Species and Reference	Study Location or Region[a]	Soil Status[b] and Sample Size	Average Length [SE][c] (cm)	Range of Lengths (cm)	Average Diameter H/V[d] [SE] (cm)	Range of Diameters H/V (cm)	Average Volume [SE] (L)	Range of Volumes (L)	Maximum Depth (cm)	Average Depth [SE] (cm)	Range of Depths (cm)
Badger (*Taxidea taxus*)											
Anderson and Johns (1977)									150		
McKenzie et al. (1982)	NR								>200*		
Lindzey (1976) (natal dens)	Idaho Utah	U (n=2)		450**					230		130 to 230
Gano and States (1982)	NR								150*		
Cline et al. (1982)	NR								150*		
Deer mouse (*Peromyscus maniculatus*)											
Reynolds and Laundre (1988)	INL Site	D (n=17)					1.3 [0.9[e]]		50		
Reynolds and Laundre (1988)	INL Site	U (n=26)					1.7 [1.8[e]]		50		
Reynolds and Wakkinen (1987)	INL Site	U (n=26)	132 [107[e]]	30 to 470			1.7 [1.8[e]]	0.3 to 7.7	50	24 [11[e]]	13 to 50
Reynolds and Wakkinen (1987)	NR								<60*		
Laundre (1989a)	INL Site	NR (n=18)			6.1[0.5]/3.8[0.2]	1.9 to 10.5/1.5 to 5.2					
Great Basin pocket mouse (*Perognathus parvus*)											
Gano and States (1982)	NR								193*		35 to 193*
Cline et al. (1982)	NR								61*		35 to 61*
Cline, Gano and Rogers (1980)	Washington*										110 to 150*
Landeen and Mitchell (1981)	Washington	D (n=7)					6.8[2.97]	2.6 to 10.8		76.9[13.7]	
Landeen and Mitchell (1981)	Washington	D (n=9)					2.8[1.4]	1.2 to 5.4		36.1[13.7]	
Landeen and Mitchell (1981)	Washington	U (n=25)						0.3 to 11.2		44.4	
Harvester ant (*Pogonomyrmex salinus*[f]) also *Pogonomyrmex occidentalis, owyheei*											
Gaglio et al. (1998)	INL Site	NR (n=19)							230	138	80 to 230
Blom et al. (1991)	INL Site										
Blom et al. (1991)	Washington*								270*		
Blom et al. (1991)	Wyoming*								270*		
Fitzner et al. (1979)	Washington	D (n=5)							270	230[20]	170 to 270

Table A-1. (continued).

Species and Reference	Study Location or Region[a]	Soil Status[b] and Sample Size	Average Length [SE][c] (cm)	Range of Lengths (cm)	Average Diameter H/V[d] [SE] (cm)	Range of Diameters H/V (cm)	Average Volume [SE] (L)	Range of Volumes (L)	Maximum Depth (cm)	Average Depth [SE] (cm)	Range of Depths (cm)
Least chipmunk (*Eutamias minimus*)											
Laundre (1989b)	INL Site	(n=5)	1.7 [0.6]	40 to 350	7.5[0.5]/4.2 [0.3]	6.5 to 8.7/3.5 to 5.2			31	17.5 [1.2]	14.4 to 20.8
Montane vole (*Microtus montanus*)											
Reynolds and Laundre (1988)	INL Site	D (n=23)					2.1 [1.5[e]]		40		
Reynolds and Laundre (1988)	INL Site	U (n=25)					1.5 [1.2[e]]		60		
Reynolds and Wakkinen (1987)	INL Site	U (n=14)	133 [82[e]]	20 to 220	NR	NR	1.1 [1.2[e]]	0.1 to 0.4	55	23 [10]	15 to 55
Reynolds and Wakkinen (1987)	NR	NR (n=2)*	1,100*							32 *	
Laundre (1989a)	INL Site and elsewhere in Idaho	NR (n=42)			4.3[0.3]/3.4[0.2]	1.1 to 7.3/0.5 to 6.7					
Northern pocket gopher (*Thomomys talpoides*)											
Winsor and Whicker (1980)	Colorado	U (n=26)								13.4[0.7]	6 to 20
Gano and States (1982)	Colorado*		3,000 (max)*								10 to 30*
Cline et al. (1982)	NR										10 to 30*
Ord's kangaroo rat (*Dipodomys ordii*)											
Reynolds and Laundre (1988)	INL Site	D (n=4)					7.3 [3.6[e]]		90		
Reynolds and Laundre (1988)	INL Site	U (n=19)					7.2 [7.7[e]]		70		
Reynolds and Wakkinen (1987)	INL Site	U (n=19)	253[233[e]]	50 to 890			7.2[7.7[e]]	1.0 to 26.3	69	34[12[e]]	20 to 69
Laundre (1989a)	INL Site	NR (n=9)			7.6 [0.8]/4.7[0.4]	5.7 to 13.2/3.7 to 7.3					
Pygmy rabbit (*Brachylagus idahoensis*)											
Wilde (1978)	INL Site	U (n=226)			12.7/NR	5.5 to 28/NR					
Wilde (1978)	INL Site	U (n=15 to 57)	140 to 200								
Townsend's ground squirrel (*Spermophilus townsendii*)[g] (also as Paiute ground squirrel)											
Reynolds and Laundre (1988)	INL Site	D (n=10)					9.4 [10.2[e]]		130		
Reynolds and Laundre (1988)	INL Site	U (n=20)					11.8 [8.4[e]]		140		

Table A-1. (continued).

Species and Reference	Study Location or Region[a]	Soil Status[b] and Sample Size	Average Length [SE][c] (cm)	Range of Lengths (cm)	Average Diameter H/V[d] [SE] (cm)	Range of Diameters H/V (cm)	Average Volume [SE] (L)	Range of Volumes (L)	Maximum Depth (cm)	Average Depth [SE] (cm)	Range of Depths (cm)
Reynolds and Wakkinen (1987) Deep burrows (≥ 120)	INL Site	U (n=3)	813[43[e]]	770 to 860			27.9 [1.8[e]]	22.8 to 29.9	138	128[9[e]]	121 to 138
Reynolds and Wakkinen (1987) Shallow burrows (≥ 60)	INL Site	U (n=17)	222[284[e]]	30 to 890			8.2 [9.7[e]]	1.2 to 16.4	55	29[12[e]]	14 to 55
Laundre (1989a)	INL Site	NR (n=10)			8.0[0.4]/5.2[0.2]	6.5 to 9.6/4.3 to 6.4					
Gano and States (1982)	NR								147*		31 to 147*
Cline et al. (1982)	NR								140 *		50 to 80*
Sagebrush vole (*Lagurus curtatus*)											
Mullican and Keller (1986)	INL Site	U (n=4)	190	70 to 460	4.8/3.2**					12.5[2.6]	8.8[6.4] to 20.3[9.8]
Mullican and Keller (1986)	NR									36*	
Mullican and Keller (1986)	NR										10 to 30*
Mullican and Keller (1986)	NR										5 to 8*
Yellow-bellied marmot (*Marmota flaviventris*)											
Gano and States (1982)	NR			600 to 800*					100*		
Svendsen (1976)	NR	NR(n=12)		380 to 440					60		40 to 60

** This value was derived from data presented in the cited reference.

* Data presented were compiled from another study by the author of the source reference, see actual references for further information.

a. NR = not reported; INL = Idaho National Laboratory.

b. D = Disturbed, U = Undisturbed, NR = Not Reported.

c. SE = Standard error.

d. Horizontal measurement or vertical measurement.

e. Standard deviation reported.

f. Previously reported as *Pogonomyrmex occidentalis* and *Pogonomyrmex owyheei*.

g. Taxonomic classification of this species is under revision (Yensen 2001).

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Appendix B

Plant Root Measurements

Appendix B

Plant Root Measurements

B-1. INTRODUCTION

A summary of root measurements for 21 plant species found at the INL Site is presented in Table B-1. The data were compiled from: (1) summaries of previously reported data, (2) original studies, and (3) data presented or interpreted by an author to support original work (noted with * in Table B-1). Root measurements that were inferred or calculated from the data presented in the cited source are indicated with ** in Table B-1.

The status of the soil profile (i.e., whether it is disturbed or undisturbed) can influence root depth and distribution. In most cases, the soil profile status (Table B-1) was either reported directly by the researcher or inferred from the description of the study site. Some investigations include data collected in both disturbed and undisturbed soil profiles, so data for each are reported separately in Table B-1. The distribution of root mass with depth for six plant species (two shrubs, three grasses and one forb) found at the INL Site is presented in Section B-2.

Table B-1. Summary of root measurements for plant species found at the INL Site.

Species or Reference	Study Location or Region[a]	Soil Status and Sample Size[b]	Maximum Depth (cm)	Average Maximum Depth (cm) [SE]	Range of Depths (cm)
Antelope bitterbrush (*Purshia tridentata*)					
Klepper, Gano, and Cadwell (1985)	Washington	D (n=4)	300	296[4]	283 to 300
Big sagebrush (*Artemisia tridentata*)[c]					
Klepper, Gano, and Cadwell (1985)	Washington	D (n=11)	250	200[12]	114 to 250
Waugh et al. (1994)	Washington	D (n=11)	230	178**	140 to 230
Abbott, Fraley, and Reynolds (1991)	INL Site	D	125		
Abbott, Fraley, and Reynolds (1991)	INL Site	U	75		
Reynolds and Fraley (1989)	INL Site	D	200		
Reynolds and Fraley (1989)	INL Site	U	225		
Anderson et al. (1987)	INL Site	D	220		
Reynolds (1990a)	INL Site	Clay (n=5)[d]		52[10.9]	40 to 60
Reynolds (1990a)	INL Site	Gr/Cob (n=7)[d]		42.5[27.5]	0 to 60
Reynolds (1990a)	INL Site	Scoria (n=7)[d]		52.9[18.9]	10 to 60
Reynolds (1990b)	INL Site	containers	120		
Link et al. (1994)	Washington	U (n=4)	195		
Hull and Klomp (1974)	Wyoming	U(n=3)*	72*		48 to 72*
Hull and Klomp (1974)	Idaho	U	72		
Foxx, Tierny, and Williams (1984)	NR	NR	914*	248*	110 to 914*
Bottlebrush squirreltail (*Elymus elymoides*)					
Abbott, Fraley, and Reynolds (1991)	INL Site	D	100		
Abbott, Fraley, and Reynolds (1991)	INL Site	U	75		
Reynolds and Fraley (1989)	INL Site	U	100		
Anderson et al. (1987)	INL Site	D	220		
Bushy birdbeak (*Cordylanthus ramosus*)					
Reynolds and Fraley (1989)	INL Site	U	160		
Bluebunch wheatgrass (*Pseudoregneria spicata*)					
McKenzie et al. (1982)	NR		200*		100 to 200*
Cheatgrass (*Bromus tectorum*)					
McKenzie et al. (1982)	NR		120*		
McKenzie et al (1982)	NR		76*		
Crested (Desert) wheatgrass (*Agropyron desertorum*)					
Abbott, Fraley, and Reynolds (1991)	INL Site	D	100		
Abbott, Fraley, and Reynolds (1991)	INL Site	U	75		
Reynolds and Fraley (1989)	INL Site	D	150		
Reynolds and Fraley (1989)	NR		183*		

Table B-1. (continued).

Species or Reference	Study Location or Region[a]	Soil Status and Sample Size[b]	Maximum Depth (cm)	Average Maximum Depth (cm) [SE]	Range of Depths (cm)
Anderson et al. (1987)	INL Site	D	220		
Reynolds (1990a)	INL Site	Clay (n=5)[c]			
Reynolds (1990a)	INL Site	Gr/Cob (n=7)[c]			
Reynolds (1990a)	INL Site	Scoria (n=7)[c]			
Hull and Klomp (1974)	Idaho	U	60		
Reynolds (1990b)	INL Site	containers	120		
Fringed sagebrush (*Artemisia frigida*)					
McKenzie et al. (1982)	Colorado		122*		
Currie and Hammer (1979)	Colorado	U (n=20)	122	<90	
Foxx, Tierny, and Williams (1984)	NR	NR	244*		46 to 244*
Gray rabbitbrush (*Chrysothamnus nauseosus*)					
Klepper, Gano, and Cadwell (1985)	Washington	D(n=9)	250	183[11]	147 to 250
Klepper et al. (1978)	Washington		240		
McKenzie et al. (1982)	Washington		240*		
Foxx, Tierny, and Williams (1984)	NR	NR	457*	293*	100 to 457*
Great Basin wildrye (*Elymus cinereus*)					
Abbott, Fraley, and Reynolds (1991)	INL Site	D	75		
Abbott, Fraley, and Reynolds (1991)	INL Site	U	100		
Reynolds and Fraley (1989)	INL Site	D	200		
Reynolds and Fraley (1989)	INL Site	U	160		
Anderson et al. (1987)	INL Site	D	220		
Reynolds (1990a)	INL Site	Clay (n=5)[c]			
Reynolds (1990a)	INL Site	Gr/Cob (n=7)[c]			
Reynolds (1990a)	INL Site	Scoria (n=7)[c]			
Reynolds (1990b)	INL Site	containers	120		
Green rabbitbrush (*Chrysothamnus viscidiflorus*)					
Klepper, Gano, and Cadwell (1985)	Washington	D(n=2)	160	153[8]	145 to 160
Abbott, Fraley, and Reynolds (1991)	INL Site	D	50		
Abbott, Fraley, and Reynolds (1991)	INL Site	U	100		
Reynolds and Fraley (1989)	INL Site	D	200		
Reynolds and Fraley (1989)	INL Site	U	190		
Indian rice grass (*Anactherum (Oryzopsis) hymenoides*)					
Klepper, Gano, and Cadwell (1985)	Washington	D(n=3)	125	119[4]	112 to 125
Reynolds and Fraley (1989)	INL Site	D	150		
Reynolds and Fraley (1989)	NR		122*		

Table B-1. (continued).

Species or Reference	Study Location or Region[a]	Soil Status and Sample Size[b]	Maximum Depth (cm)	Average Maximum Depth (cm) [SE]	Range of Depths (cm)
Jim Hill Mustard (*Sisymbrium altisimum*)					
Waugh et al. (1994)	Washington	D(n=1)	97		97
Needle and thread grass (*Stipa* sp.)					
McKenzie et al. (1982)	NR		183*		
Klepper, Gano, and Cadwell (1985)	Washington	D(n=4)	160	139[8]	122 to 160
Foxx, Tierny, and Williams (1984)	NR	NR	183*		63 to 168*
Prickly lettuce (*Lactuca serriola*)					
Klepper, Gano, and Cadwell (1985)	Washington	D (n=1)	85		
Russian thistle (*Salsola kali*)					
Waugh et al. (1994)	Washington	D(n=3)	137	123**	102 to 137
Klepper, Gano, and Cadwell (1985)	Washington	D (n=8)	209	172[11]	118 to 209
McKenzie et al. (1982)	NR		240*		
Reynolds (1990b)	INL Site	containers	120		
Salsify (*Tragopogon dubius*)					
McKenzie et al. (1982)	NR		137*		
Spiny hopsage (*Grayia spinosa*)					
Klepper, Gano, and Cadwell (1985)	Washington	D(n=1)			195
Link et al. (1994)	WA	U (n=4)	210		
Streambank wheatgrass (*Elymus lanceolatus*)					
Abbott, Fraley, and Reynolds (1991)	INL Site	D	100		
Abbott, Fraley, and Reynolds (1991)	INL Site	U	75		
Anderson et al. (1987)	INL Site	D	220		
Reynolds (1990a)	INL Site	Clay (n=5)[c]			
Reynolds (1990a)	INL Site	Gr/Cob (n=7)[c]			
Reynolds (1990a)	INL Site	Scoria (n=7)[c]			
Reynolds (1990b)	INL Site	containers	120		
Turpentine cymnopterus (*Cymnopterus terebinthinus*)					
Klepper, Gano, and Cadwell (1985)	Washington	D(n=4)	160	145[8]	124 to 160

Table B-1. (continued).

Species or Reference	Study Location or Region[a]	Soil Status and Sample Size[b]	Maximum Depth (cm)	Average Maximum Depth (cm) [SE]	Range of Depths (cm)
Yellow sweet clover (*Melilotus officinalis*)[c]					
McKenzie et al. (1982)	NR	NR	137*		
Foxx, Tierny, and Williams (1984)	NR	NR	152*		85 to 152*

* Data presented were compiled from another study by the author of the source reference, see actual references for further information.

** This value was derived from data presented in the cited reference.

a. NR = not reported, INL = Idaho National Laboratory.

b. D = disturbed, U = undisturbed, NR = not reported.

c. Plants grown in containers containing clay, gravel/cobble (Gr/Cob), or scoria.

B-2. ROOT DISTRIBUTION WITH DEPTH

The distribution of root mass with depth has been compiled for big sagebrush (*Artemisia tridentata*) (Table B-2), crested wheatgrass (*Agropyron desertorum* and A. *cristatum*) (Table B-3), streambank wheatgrass (*Elymus lanceolatus*) (Table B-4), Great Basin wildrye (*Elymus cinereus*) (Table B-4), and Russian thistle (*Salsola kali*) (Table B-5). Distribution of root densities with depth is presented for three species including big sagebrush, gray rabbitbrush, and Russian thistle (Table B-6).

Table B-2. Distribution of big sagebrush roots with depth.

Hull and Klomp (1974)		Branson, Miller and McQueen (1976)[d]		Reynolds (1990b)[e]			Klepper, Gano, and Cadwell (1985)[d]		Sturges 1977[d]	
Depth (cm)[a]	Percent Total Root Mass[b]	Depth (cm)	Percent Total Root Mass	Depth (cm)	Mean Mass (g)	Percent Total Root Mass	Depth (cm)	Percent Total Root Mass	Depth (cm)	Percent Total Root Mass
0 to 15	53	0 to 20	40	0 to 20	130	22	0 to 50	70	0 to 30	63
15 to 30	20	20 to 40	25	20 to 40	62	11	50 to 100	24	30 to 60	25
30 to 46	7	40 to 60	15	40 to 60	81	14	100 to 150	5	60 to 90	8
46 to 61	7	60 to 80	10	60 to 80	111	19	150 to 200	1	90 to 120	3
61 to 76	4	80 to 100	5	80 to 100	114	20			120 to 150	2
76 to 91	3	100 to 120	<5	100 to 120	86	15			150 to 180	<1
91 to 107	3								180 to 210	<1
107 to 122	1									
122 to 137	1									
137 to 152	1									
152 to 183	T[c]									

a. Original data reported in inches.

b. Averages for four plants.

c. Only traces of roots detected in this interval.

d. Data compiled by Reynolds (1990a).

e. Study plants were grown in containers.

Table B-3. Distribution of crested wheatgrass roots with depth.

Reynolds (1990b)[a]			Caldwell and Richards (1986)[b]		Hull and Klomp (1974)		
Depth (cm)	Mean Root Mass (g)	Percent Total Root Mass	Depth (cm)	Percent Total Root Mass	Depth (cm)	Percent Total Root Mass[c]	Percent Total Root Mass Beneath Sagebrush[d]
0 to 20	187	24	1 to 15	35	0 to 15	69	62
20 to 40	81	11	15 to 30	25	15 to 30	15	17
40 to 60	91	12	30 to 50	13	30 to 46	9	12
60 to 80	152	20	50 to 80	13	46 to 61	3	6
80 to 100	139	18	80 to 100	13	61 to 76	1	2
100 to 120	124	16			76 to 91	1	1
					91 to 107	1	T
					107 to 122	1	
					122 to 137	T[e]	
					137 to 152	T	
					152 to 183		

a. Study plants were grown in containers.
b. Data compiled by Reynolds (1990a).
c. Average of two plants not growing beneath sagebrush.
d. Average of three plants growing beneath sagebrush.
e. Only traces of roots were detected in this interval.

Table B-4. Distribution of root mass with depth for streambank wheatgrass and Great Basin wildrye (Reynolds 1990a).

	Streambank Wheatgrass[a]		Great Basin Wildrye[a]	
Depth (cm)[a]	Mean Root Mass (g)	Percent Total Root Mass	Mean Root Mass (g)	Percent Total Root Mass
0 to 20	133	21	207	28
20 to 40	72	12	63	9
40 to 60	77	13	86	12
60 to 80	126	20	137	19
80 to 100	120	19	146	20
100 to 120	92	15	96	13
Totals	621g	100%	735g	100%

a. Study plants were grown in containers.

Table B-5. Distribution of roots of Russian thistle with depth.

Reynolds (1990b)[a]			Klepper, Gano, and Cadwell (1985)[b]	
Depth (cm)	Mean Root Mass (g)	Percent Total Root Mass	Depth (cm)	Percent Total Root Mass
0 to 20	118	16	0 to 50	72
20 to 40	109	14	50 to 100	22
40 to 60	85	12	100 to 150	5
60 to 80	150	21	150 to 200	<1
80 to 100	186	26		
100 to 120	90	12		

a. Study plants were grown in containers.

b. Data compiled by Reynolds (1990a).

Table B-6. Root density with depth for three species from Klepper, Gano, and Cadwell (1985).

Depth (cm)	Root Density (g/dm^3)		
	Big sagebrush	Gray Rabbitbrush	Russian Thistle
50	0.144	0.039	0.17
100	0.049	0.065	0.052
150	0.011	0.014	0.012
200	0.003	0.005	
250	0	—	

— = not sampled.

B-3. REFERENCES

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Appendix C

Modeling Example Using Parameter Input Specific to the Idaho National Laboratory Site

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Modeling Example Using Parameter Input Specific to the Idaho National Laboratory Site

C-1. INTRODUCTION

The enhancement of waste transport through biointrusion activities that move contaminants to the surface has been investigated as part of the Waste Area Group 7 Interim Risk Assessment (IRA) (Becker et al. 1998). In that assessment, the DOSTOMAN biotic transport model was used to predict surface soil concentrations resulting from the movement of contaminants buried in the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) to the surface by plant uptake and animal burrowing.

This appendix provides an example of how portions of the data presented in Appendices A and B of this report were used as input for the DOSTOMAN simulations. The assumptions used in the DOSTOMAN simulations (e.g., depth intervals, animal populations, plant composition) may or may not be appropriate for other models. The following sections are summarized from the IRA and data were originally compiled in an engineering design file (Hampton and Bensen 1996), which included a subset of the larger data set presented in this report. A detailed discussion of the DOSTOMAN biotic model can be found in the IRA.

C-2. BACKGROUND

The following general assumptions were incorporated into the DOSTOMAN biotic model (from Becker et al. 1998):

- Waste was distributed homogeneously across the SDA
- The current disturbed habitat would return to native habitat in 200 years
- Measures to control shrub establishment and cap integrity would be maintained throughout the institutional control period.

The amount of contaminant mass available was 37.6% of the mass released from the source term model. The partial mass reflects the burial of most of the waste at depths deeper than plant roots or animal burrows are expected to penetrate. The maximum depth of biotic intrusion was assumed to be 2.70 m (8.86 ft) based on the maximum depth of harvester ant nests (Fitzner et al. 1979). The average depth to basalt is 5.26 m (17.25 ft) with 1.52 m (5 ft) of overburden (the depth of overburden based on weighted-average measurements collected on the SDA) and 0.61 m (2 ft) of underburden (based on current operational practices). The average waste thickness was, therefore, assumed to be 3.13 m (10.25 ft). Because the upper levels of intrusion occur in the 1.52 m (5 ft) of overburden, only 1.18 m (3.86 ft) (8.86 -5.00) or 37.6% (3.86/10.25) of the contaminant mass was assumed to be available for plant uptake and translocation by burrowing.

Burrow and plant root distribution data were reconfigured to coincide with the eight compartment divisions for which contaminant concentrations were modeled:

Depth (cm)
1 to 15
15 to 30
30 to 45
45 to 90
90 to 135
135 to 180
180 to 225
225 to 270.

Both plant contaminant uptake and release through plant death were modeled. Burrowing animal intrusion and burrow collapse, as well as leaching and radioactive decay, were incorporated into the model. The soil concentrations in the 0 to 15-cm (0 to 0.5-ft) compartment were used to represent surface concentrations for this screening. The maximum concentrations calculated in the compartments between 15 cm (0.50 ft) and 270 cm (8.86 ft) were used to represent subsurface concentration levels.

The current scenario (year 2000) was analyzed to provide an estimate of current risk to ecological receptors for use in the feasibility study (FS). A 100-year scenario (1996 to 2095) was also evaluated to provide an estimate of soil concentrations at the time of hypothetical release from institutional control.

C-3. ANIMAL BURROWING ANALYSIS

Burrowing species composition, population density, burrow volumes, and maximum burrow depths reflecting estimated current burrowing activity on the SDA are shown in Table C-1. Burrow distribution with depth for individual species is listed in Table C-2. Only harvester ants and the Great Basin pocket mouse were expected to attain burrow depths sufficient to exceed the current overburden thickness of 150 cm (calculated average). The maximum burrow depth is 270 cm for harvester ants and 193 cm for the pocket mouse. Species densities are based primarily on SDA studies (Groves 1981; Groves and Keller 1983; Koehler 1988; Boone 1990; Boone and Keller 1993). Burrow volume, depth, composition, and average population densities were assumed to remain constant for 100 years, assuming maintenance of current conditions through institutional controls over that period.

To simulate conditions at the site if institutional controls were discontinued, the composition of the animal community was altered to reflect change as the vegetation community is transformed. The species composition, burrow depth, volume, and density for the 100+ year modeled periods are summarized in Table C-3. The fractional burrow distribution for each individual species is presented in Table C-4. While rodent populations fluctuate widely from year to year (Boone and Keller 1993), population densities presented herein are average species compositions and population levels over time.

Table C-1. Small animal density and burrowing parameters—current scenario.

Burrowing Animal Species[a]	Population (individuals/ha)[a]	Maximum Depth (cm)	Soil Mass per Burrow (kg)[b]	Number of New Burrows (per year)[c]
Townsend's ground squirrel	**5**	**138**[b]	**43.7**	0.75
Ord's kangaroo rat	**5**	**90**[b]	**14.7**	0.87
Deer mouse	**17**	**50**[b]	**3.6**	0.87
Montane vole	**30**	**40**[b]	**4.5**	0.87
Great Basin pocket mouse	**15**	193[c]	**4.5**	0.75
Western harvester ant nests	**13**[d]	270[e]	3.6[e]	0.1[d]

Note: Data in bold are INL site-specific.

a. Mammal species composition and populations based on studies by Groves (1981), Groves and Keller (1983), Koehler (1988), Boone (1990), Boone and Keller (1993).

b. Reynolds and Laundre (1988); Reynolds and Wakkinen (1987) using a soil bulk density of 1.5 g/cm^3 from Binda (1981).

c. McKenzie et al. (1982).

d. Blom, Clark, and Johnson (1991).

e. Fitzner et al. (1979).

Table C-2. Burrow volume and fraction of volume excavated at depth by small animals—current scenario.

Depth (cm)	Townsend's Ground Squirrel[a]	Ord's Kangaroo Rat[a]	Deer Mouse[a]	Montane Vole[a]	Great Basin Pocket Mouse[b]	Western Harvester Ants[c]
Soil type	Disturbed	Disturbed	Disturbed	Disturbed	Disturbed	
0 to 15	**0.045**	**0.16**	**0.38**	**0.46**	0.21	0.21
15 to 30	**0.072**	**0.13**	**0.29**	**0.46**	0.21	0.21
30 to 45	**0.034**	**0.23**	**0.25**	**0.07**	0.21	0.21
45 to 90	**0.24**	**0.47**	**0.08**	**0**	0.23	0.15
90 to 135	**0.6**	**0**	**0**	**0**	0.08	0.90
135 to 180	**0.12**	**0**	**0**	**0**	0.05	0.60
180 to 225	**0**	**0**	**0**	**0**	0.02	0.40
225 to 270	**0**	**0**	**0**	**0**	0	0.30
Total burrow volume (L)	**29.2**	**9.8**	**2.4**	**2.7**	3.0	2.4

Note: Data in bold are INL site-specific.

a. Reynolds and Laundre (1988); Reynolds and Wakkinen (1987).

b. McKenzie et al. (1982).

c. Fitzner et al. (1979).

Table C-3. Small animal density and burrowing parameters for SDA 100+ year scenario (disturbed soil).

Species[a]	Number per Hectare[a] Current/100+year	Maximum Depth (cm)	Soil Mass per Burrow (kg)[b]	New Burrows ($year^{-1}$)[c]
Badger	1/1	250	252.5	2
Deer mouse	**17/30**	**50**[b]	**6.6**	0.87
Great Basin pocketmouse	**15/25**	193[c]	**4.5**	0.75
Least chipmunk	**3/8**	**31**[f]	10.5	0.75
Montane vole	**30/10**	**55**[b]	**7.5**	0.87
Northern pocket gopher	**7/7**	100	4.1	0.75
Ord's kangaroo rat	**8/5**	**90**[b]	**21.6**	0.87
Rabbits	8/20	150	52.7	0.75
Townsend's ground squirrel	**5/5**	**138**[b]	**48.9**	0.75
Western harvester ants	20/36[d]	270[e]	3.6[e]	0.1

Note: Data in bold are INL site-specific.

a. Groves (1981), Groves and Keller (1983), Koehler (1988), Boone (1990), Boone and Keller (1993).

b. Reynolds and Laundre (1988), Reynolds and Wakkinen (1987) using a soil bulk density of 1.5 g/cm^3 is from Binda (1981).

c. McKenzie et al. (1982).

d. Blom, Clark, and Johnson (1991).

e. Fitzner et al. (1979).

Table C-4. Burrow volume and fraction of volume excavated at depth by small animals—100+ year scenario.

Depth (cm)	Townsend's Ground Squirrel[a]	Ord's Kangaroo Rat[a]	Deer Mouse[a]	Voles[a]	Great Basin Pocket Mouse[b]	Northern Pocket Gopher[b]	Least Chipmunk[c]	Badger[b]	Rabbits[d]	Western Harvester Ants
Soil Type	Disturbed	Disturbed	Disturbed	Disturbed	Disturbed					
0 to 15	**0.08**	**0.21**	**0.22**	**0.17**	0.21	0.23	**0.38**	0.21	**0.17**	0.21
15 to 30	**0.18**	**0.29**	**0.44**	**0.23**	0.21	0.23	**0.38**	0.21	**0.17**	0.21
30 to 45	**0.08**	**0.14**	**0.25**	**0.27**	0.21	0.23	**0.23**	0.21	**0.17**	0.21
45 to 90	**0.11**	**0.36**	**0.09**	**0.2**	0.23	0.26	**0**	0.19	**0.17**	0.15
90 to 135	**0.52**	0	0	0	0.08	0.04	**0**	0.07	**0.17**	0.09
135 to 180	**0.03**	0	0	0	0.05	0	**0**	0.05	**0.15**	0.06
180 to 225	**0**	0	0	0	0.02	0	**0**	0.04	**0**	0.04
225 to 270	**0**	0	0	0	0	0	**0**	0.03	**0**	0.03
Total burrow volume (L)	**29.2**	**9.8**	**2.4**	**2.7**	3	2.7	**7.0**	168	**35**	2.4

Note: Data in bold are INL site-specific.

a. Reynolds and Laundre (1988).

b. McKenzie et al. (1982).

c. Laundre (1989a, 1989b).

d. Wilde (1978).

e. Fitzner et al. (1979).

C-4. VEGETATION COMMUNITY SUCCESSION

Plant age composition for current and future scenarios was assumed to remain constant over the modeled periods. Biomass calculations were based on a total community production and fractional contributions of individual plant species (NRCS 1981). Successional transition of the SDA from the current vegetation community was assumed to result in a natural community similar to sagebrush-grass communities surrounding the RWMC and other parts of the region (Anderson 1991; Anderson and Inouye 1988; NRCS 1981).

The current vegetation cover on the SDA mainly consists of two species: crested wheatgrass (*Agropyron cristatum*) and Russian thistle (*Salsola kali*) (Arthur and Markham 1982). Biomass and rooting depths for these species are summarized in Table C-5. The total community biomass (aboveground and belowground) was estimated as approximately 11,000 kg/ha for SDA current conditions (Arthur and Markham 1982).

The composition was assumed to remain constant through 100 years of maintenance of current conditions. The establishment of sagebrush and other deeper rooting shrub species is controlled on the SDA; therefore, species other than crested wheatgrass and Russian thistle were not included in the current scenario model. The maximum rooting depth for crested wheatgrass was not expected to reach a depth sufficient to penetrate the waste matrix during the current scenario, but Russian thistle can penetrate into the waste zone. Rooting depths and root mass distribution are summarized on Table C-6.

The 100+ year scenario for vegetation consists of several phases in which transitional changes in the current SDA community composition result in the reestablishment of a natural sagebrush-bunchgrass community (Anderson and Inouye 1988; Anderson et al. 1978; NRCS 1981). Species composition for communities modeled after 100 years is presented in Table C-5. The table summarizes the individual species biomass and maximum rooting depth for each of the transitional phases. Composition and percent biomass for successional increments are based on Arthur and Markham (1982), Anderson and Inouye (1988), Hull and Klomp (1974), Anderson et al. (1978), and Anderson (1991). Biomass calculations for the three periods were based on average yearly aboveground estimates of 1,490 kg/ha, 2,030 kg/ha, and 1,000 kg/ha. Root mass and distribution with depth for this scenario are given in Table C-7. Maximum rooting depths were expected to be attained by sagebrush and similar shrubs (gray rabbitbrush [*Chrysothamnus nauseosus*]), with maximum shrub density developing at 200 years.

Table C-5. Estimated parameters for the uptake of plant species for the SDA—current and 100-year to 200-year+ scenarios.

Plant Species	Root to Shoot Ratio	Fraction Litterfall (year^{-1})d	Fraction Root Death (year^{-1})[b]	Current Scenario: Maximum Root Depth (cm)	Current Scenario: Fraction of Total Biomass[g]	100yr+ Scenarios: Maximum Root Depth (cm)	100yr+ Scenarios: Fraction of Total Biomass 130 years[l]	100yr+ Scenarios: Fraction of Total Biomass 150 years[l]	100yr+ Scenarios: Fraction of Total Biomass 200 years+[l]
Crested wheatgrass	8[a]	1	0.5	**150**[e]	**0.75**	75[h]	**0.55**	**0.30**	—
Russian thistle	1.4[b]	1	1	172[f]	**0.25**	172[f]	**0.15**	—	—
Sagebrush	1.3[a]	0.50[e]	0.5	—	—	225[e]	**0.05**	**0.10**	**0.20**
Green rabbitbrush	1.3[a]	0.85[e]	0.5	—	—	200[e]	**0.11**	**0.06**	**0.05**
Bluebunch wheatgrass	8[a]	1	0.5	—	—	160[e]	**0.03**	**0.15**	**0.35**
Needle and thread grasses	9[c]	1	0.5	—	—	183[i]	**0.02**	**0.09**	**0.10**
Other grasses	9[c]	1	0.5	—	—	200[i,j]	**0.05**	**0.10**	**0.04**
Forbs	1.5[b]	1	0.8[d]	—	—	160[e]	**0.02**	**0.10**	**0.15**
Other shrubs	1.5[b]	1	0.8[d]	—	—	240[k]	**0.02**	**0.10**	**0.11**
	Community aboveground biomass (kg/ha)				**1,490**		1,490	2,030	1,000
	Community root-to-shoot ratio				**6.35**		5.57	5.70	5.22

Note: Data in bold are INL site-specific.

a. Hull and Klomp (1974).

b. Becker et al. (1994).

c. Pearson (1965).

d. Estimate based on root -to-shoot and fractional root depths for grass and shrub species presented in Becker (1994).e. Reynolds and Fraley (1989).

f. Klepper, Gano, and Caldwell (1985).

g. Arthur 1982; Arthur and Markham (1982).

h. Abbott, Fraley, and Reynolds (1991).

i. Mckenzie et al. (1982).

j. McKenzie et al (1986).

k. For gray rabbitbrush from Klepper et al. (1979).

l. Composition and percent biomass based on successional increments based on data presented in Arthur (1982); Anderson and Inouye (1988); Anderson (1991).

Table C-6. Fractional root distribution for individual plant species—current scenario.

Depth (cm)	Crested Wheatgrass[a]	Russian Thistle[a]
0 to 15	**0.35**	**0.22**
15 to 30	**0.25**	**0.21**
30 to 45	**0.10**	**0.21**
45 to 90	**0.23**	**0.23**
90 to 135	**0.04**	**0.10**
135 to 180	**0.03**	**0.02**
180 to 225	**0**	**0.02**
225 to 270	**0**	**0**

Note: Data in bold are INL site-specific.

a. Reynolds (1990).

Table C-7. Fractional root distribution for individual plant species—100+ year scenario.

Depth (cm)	Crested Wheatgrass[a]	Russian Thistle[a]	Sagebrush[a]	Green Rabbitbrush[b]	Bluebunch Wheatgrass[a]	Needle and Thread Grasses[a]	Other Grasses[a]	Forbs[a]	Other Shrubs[b]
0 to 15	**0.35**	**0.22**	**0.21**	0.125	**0.35**	**0.35**	**0.35**	**0.22**	0.12
15 to 30	**0.25**	**0.21**	**0.20**	0.100	**0.25**	**0.25**	**0.25**	**0.21**	0.10
30 to 45	**0.1**	**0.21**	**0.20**	0.07	**0.1**	**0.10**	**0.105**	**0.21**	0.07
45 to 90	**0.23**	**0.23**	**0.23**	0.45	**0.23**	**0.20**	**0.23**	**0.23**	0.45
90 to 135	**0.04**	**0.1**	**0.13**	0.20	**0.04**	**0.05**	**0.03**	**0.10**	0.20
135 to 180	**0.03**	**0.02**	**0.015**	0.04	**0.03**	**0.03**	**0.03**	**0.02**	0.04
180 to 225	**0**	**0.02**	**0.01**	0.015	**0**	**0.02**	**0.005**	**0.01**	0.015
225 to 270	**0**	**0**	**0.005**	0	**0**	**0**	**0**	**0**	0.005

Note: Data in bold are INL site-specific.

a. Reynolds (1990).

b. McKenzie et al. (1982).

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